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CONSTRUCTION INDUSTRY
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OF THE
CRITICAL PATH METHOD

by

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B.S., United States Naval Academy
(1962)

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE
DEGREE OF MASTER OF
SCIENCE

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

February, 1965

Signature of Author ______________________________
Department of Civil Engineering, February, 1965

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ABSTRACT

CONSTRUCTION INDUSTRY
USER FEEDBACK ANALYSIS
OF THE
CRITICAL PATH METHOD

LT(JG) SALVATORE A. MARTINELLI, CEC, USN

Submitted to the Department of Civil Engineering on 10 January 1965 in partial fulfillment of the requirements for the degree of Master of Science.

This thesis in general explores and develops the overall thoughts of a large group of major construction firms with regard to the Critical Path Method, in an attempt to gather the opinions of the construction industry on a whole. It also explores the actual CPM procedures currently in use and makes recommendations as to possible improvements.

The interview concept, both written and oral, was employed as the method of research and data collection, with thirty-one companies participating. A most carefully devised questionnaire was composed and was used exclusively during the research phase. In order to obtain a conclusive sample, the firms contacted were of varying size, operated throughout the world, and specialized in all the major construction fields.

After having gathered all the opinions and procedures, the combined data were analyzed in terms of nine major topics of application. The consensus of the companies was recorded in each of the fields, any possible general trends were illustrated, and conclusions and recommendations were then presented.

All the general concepts were then summarized in a company simulation of CPM use, intended for study by any construction company.

Thesis Supervisor: Albert G. H. Dietz

Titles: Professor of Civil Engineering and
Professor of Architecture

ACKNOWLEDGMENTS

The author wishes herein to express his deep and most sincere appreciation to Professor Albert Dietz for his very helpful advice, assistance, suggestions, and, at times, needed encouragement.

The author is further deeply indebted to the many corporate executive officers of the construction firms which form the sub-grade or supporting pedestal for this paper. Their invaluable experiences and words of wisdom in reality are the paper, and without such sincere and valuable cooperation this work would not at all be possible.

In addition the helpful comments and reviews of my fellow officers, LT. Robert A. Schade, CEC, USN and LT. Jerry L. Horacek, USN proved most useful.

The author deeply thanks his wife, Jill, for her assistance in proof-reading and her continual inspirational aid, without which the final result would surely have been of less value.

Last, but by far not at all least, great apprecation is rendered to Mrs. Charles Hayde for her perseverance and competent preparation of the manuscript into its final form.

Despite all the above assistance I retain complete responsibility for any errors which possibly remain herein, and all editorial concepts presented.

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CONSTRUCTION INDUSTRY
USER FEEDBACK ANALYSIS
OF THE
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CHAPTER 1

INTRODUCTION

1.1 Background

Since the advent of the construction tool known commonly as the Critical Path Method or Critical Path Scheduling, there has been expressed on the part of many influencial organizations a great desire that this method be more or less universally accepted by all construction firms, regardless of size or prime area of operation. The Critical Path Method, hereinafter referred to as CPM, has been described in much detail in almost all construction industry or civil engineering periodicals and bulletins. While such published articles do readily admit that the concepts involved in CPM are indeed a marked departure from traditional ideas with regard to project planning and control; none, if any, has attempted to actually delineate the areas of usefulness of CPM, nor its possible shortcomings or pitfalls.

Most such descriptive papers have attempted to illustrate the power of CPM by means of the normally useful precept and example concept. Such articles usually pass along their information by documenting for the reader the actual experiences of a particular construction company

on a particular project in utilizing CPM. While this approach is of great value to the very few other projects which exactly fall into the area of the example job, it is consequently of little value to the vast majority of other varied construction companies, due in no small part to the inherent very diverse nature of the construction industry itself.

1.2 Shortcomings of Past Documentary Approaches

The shortcomings of the above described methods of promulgating CPM fall into two possibilities. The first of these is that such articles deal only with successful applications of CPM on some type of construction work. Thus a picture is presented to the reader which could lead him to believe that CPM could prove to be a sort of panacea in the area of construction control. This, of course, is far from the method's purpose or true worth. The reader is rarely introduced to areas of CPM failure or those of less than outstanding success. Thus he is completely unaware of many possibilities for financial or operational disaster which could result from improper CPM utilization, at least until he first attempts its use in such a blind manner.

The second shortcoming of past papers concerns the aspects of construction diversity. Is a heavy construction contractor able to effectively reach a conclusion concerning the applicability of CPM in his field by means of reading the results attained by a building contractor using CPM on a rehabilitation project? Except for the most general aspects, one would probably think not.

1.3 Purpose and Scope

The primary purpose of this comprehensive paper will be to eliminate the above two CPM evaluation shortcomings in an attempt to allow the construction industry at large to be able to reach its own objective conclusions concerning the applicability of this method at the level of the individual firm, regardless of its size or theatre of operations.

1.4 Method

This goal is accomplished by means of feedback from the construction industry itself, through the medium of the personal or corresponded interview. The firms contacted are engaged in all the possible areas of construction, with operations around the world, and financially range from the very small to the true giants of construction. By means of a scientifically deduced questionnaire responses are received, collated, and evaluated in order to produce true and objective results for the ultimate benefit of the construction industry itself. In conclusion, this paper treats CPM as a method for the use of the construction industry at large and attempts to actually pinpoint its areas of true value and its possible serious defects as well.

1.5 Why a Paper on CPM?

The reader may ask with justification why such emphasis is being placed and exerted in the area of CPM? Today's increased tempo and complexity of construction operations place a definite added strain on

the conventional methods of planning and scheduling. In construction, heavy, industrial, or commercial, all are familiar with the standard method of scheduling projects by the use of bar charts, or the more sophisticated model, the Gannt chart. Granted that these methods have performed their tasks well and adequately, how often has a project manager or his crew wished for a less limited and more sophisticated method of scheduling that would graphically illustrate on paper the way a large construction project ties together? One that would further attempt to pinpoint supply delivery and sub-contractors starting dates; and write engineers' specifications into the schedule. In addition, is there a means for providing data for calculating manpower requirements by trades or for making financial forecasts at any given stage of the project at hand? It has been stated by some that the Critical Path Method is just the solution to all the above listed problems. Is it just that? It is hoped that this paper will answer some or all of these questions to the satisfaction of the reader.

CHAPTER 2

EVOLUTION OF CPM

2.1 Purpose of Historical Description

The author makes the assumption in writing this paper that all readers are concerned with the construction industry in some manner and, therefore, are at least vaguely familiar with the basic rudiments of CPM. For the purposes of completeness, however, this chapter will briefly describe the evolution of CPM and will also present a few examples of its possible intended uses. One word of warning is in order. As the reader progresses through this chapter he is earnestly cautioned against developing ideas of CPM as a possible panacea. This it just is not!

2.2 Early Efforts and Formulation

Critical path is generally accepted as having had its beginning at the E. I. duPont de Nemours Company of Wilmington, Delaware in 1957 under the direction of Mr. J. E. Kelley of the Rand Corporation, who was hired in an attempt to devise a method of planning, scheduling, and coordinating new plant construction. A new method in the area was formulated and tested at duPont on a ten million dollar project, and was further tested on several other projects in the following year with good results.

2.3 Mathematical Formulation

In December of 1959 Kelley and Mr. Walker of duPont published an initial formulation of the CPM concept. The first solution to this problem was published by D. R. Fulkerson of the Rand Corporation in January, 1961, working with the dual of the problem and a slight variation of a network flow method. Kelley then followed with his solution the following summer.

2.4 PERT

At about this same time the Special Projects Office of the United States Navy contracting with the consulting firm of Booz-Allen and Hamilton was working toward an intricate scheduling and control system for the development of the Polaris missile under the direction of Vice Admiral W. Raborn, USN. When formulated, this system was called Program Evaluation and Review Technique. The fact that the Polaris program was completed well in advance of schedule was in no small part due to the results of PERT. This system utilized most probable durations to some degree in its applications. As a result of PERT'S first success, it is now required on all major projects for all services.

2.5 The Arrow Diagram

All construction projects, regardless of complexity, must be subdivided for planning purposes into a series of segments dealing with the various aspects or types of construction processes. These spheres may be further broken down into individual activities of work

such as excavate for footings, form set-up, pour concrete, strip forms, etc. For CPM use this is exactly the procedure, with the starts and completions of these activities labeled as events. An example of an event would be the time when a concrete curtain wall is completely poured. The level of detail herein implied is entirely variable. As a simple illustration, the start of steel erection and its finish are events, while the actual erection is an activity. The events could be considered as progress markers along the duration of a project.

The Arrow diagram shows the relationships between these activities in a head to tail mode, with the diagram usually not drawn to scale. In this model the arrow head and tail represent events while the arrow, itself, represents an activity; further, the head of the arrow indicates the completion of that activity. The sequence of arrows indicates the sequence of actual work; that is, activities originating at each node cannot be started until all activities terminating at that node are completed.

The following figure illustrates an Arrow diagram in an adequate manner. The figure presents a project with five activities. Note that

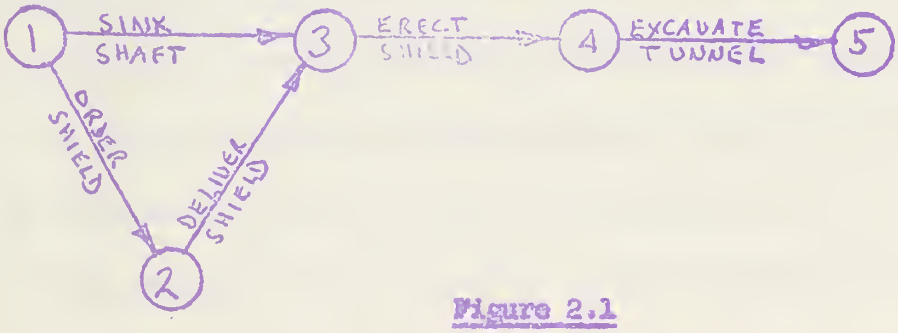

Figure 2.1

there the events are numbered in consecutive order. This is not at all a requirement, except for some computer programs. It may be seen that event number three is the time at which the shaft must be sunk and the shield delivered, as well as the point in time at which the erection of the shield may be commenced.

2.6 Arrow Diagram Needs

In order to properly construct an arrow diagram one must necessarily know or devise the activities that comprise the project and the restraints that will determine the sequence of activities. The restraints are those common to construction, namely: management, physical, and crew restraints. Often two activities could presumably commence at the same point in time; however, space, safety or lack of manpower could prevent this simultaneous operation. Decisions must then be made by management as to the correct planned order of activities.

2.7 The Addition of Costs

By proper uses of the above explained arrow diagram, some of the advantages of CPM may be brought forth. These are answers to the questions as to which activities should be speeded up, how much, and at what cost. If an operation is performed with a certain crew of workers over a particular time duration at what is considered to be the efficient mix, such a period is classified as the "normal time" for the execution of said operation. When management elects to decrease this duration, through the addition of men and machines,

with a resulting efficiency decrease, the unit costs correspondingly increase. Such a process is referred to as "crashing", and reaches a limit when further time decreases result in increased costs which approach infinity. This point is determined by many factors which are most familiar to the industrial operations engineer or "time and motion" personnel. See figure 2.2.

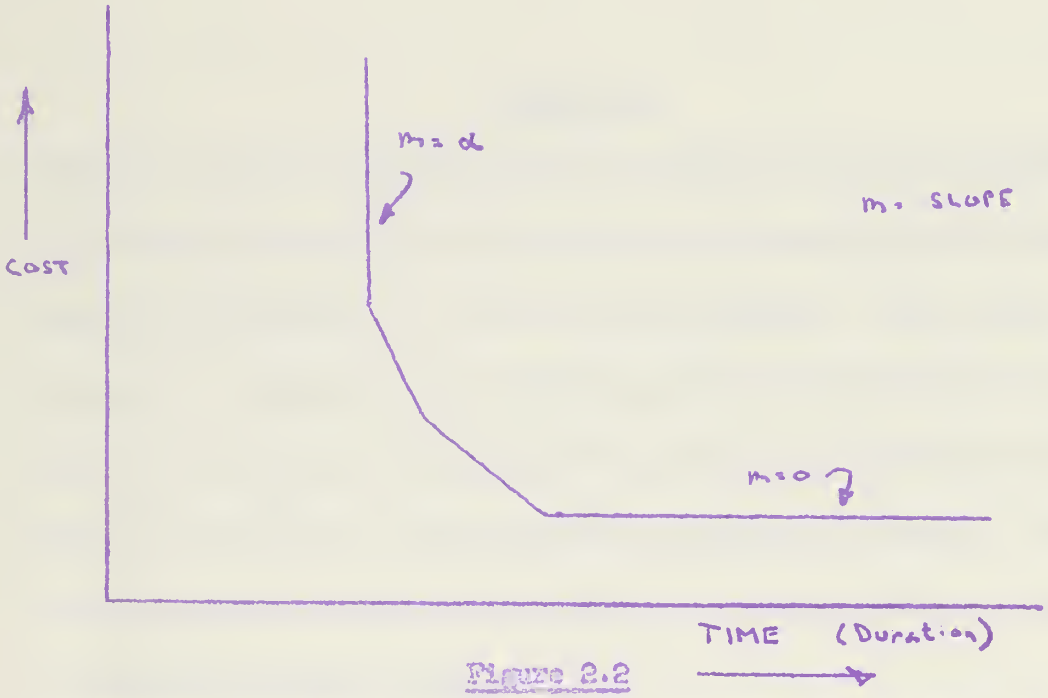

Figure 2.2

Figure 2.2 is much simplified for illustrative purposes, but it does present the primary concepts of crashing. When one reaches the slope point of infinity, further crashing is undesirable. When costs are to be implemented in CPM uses, the following information is included on each activity on the arrow diagram: normal time, normal costs, crash time, and crash costs. All costs are expressed on a per day unit cost basis, in order to aid one in crashing calculations.

See figure 2.3. The information on these activities allows one to

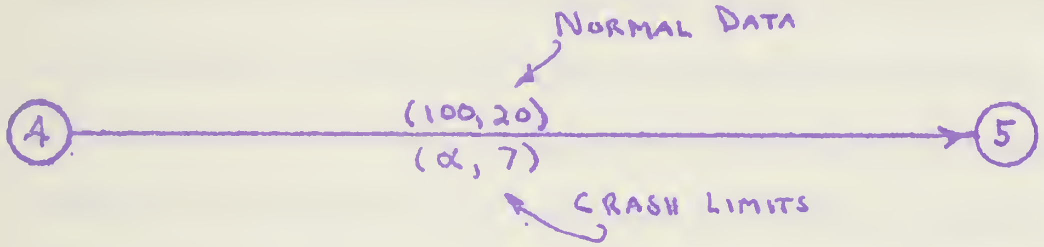

Figure 2.3

manipulate the flow network in order to arrive at the best over-all work schedule with regard to time and costs, depending upon the factor which is more important on each particular project. This is done by the use of a schedule spectrum beginning with all activities at normal time, with activities being crashed by means of an iterative procedure using, in most cases, a pre-prescribed algorithm for this use. The ultimate schedule presents all activities at crash positions, within the allocated economic limits.

2.8 Float

Let us now briefly turn to the topic of floats. If, in a particular network, an activity is allocated more time than is required to complete the task, this excess time is called "float". In CPM there exist four types of float, whose differences will not be dealt with in this paper. Float actually occurs when the times

to arrive at a particular node differ over two or more paths. Any activities which have zero float are termed critical, and they are along the critical path. This means that if any of said activities are lengthened, the entire job duration will also be increased. It is recommended that in performing project scheduling, that critical activities be scheduled first, based upon the amount of float, if any, available.

2.9 CPM Non-cost Uses

CPM project networks will give results which are the developed schedules alone, or with the inclusion of crash cost data and calculations, the project cost calculations will also be derived. Based upon the very many unpredictable aspects of construction, the latter refinement process is but very seldom utilized. More will be said on this matter later in this paper.

2.10 Conclusion

This chapter is not at all intended to be an all-inclusive description of uses and methods of the critical path concept. Actually, in all truthfulness it is far from such a teaching aid. Its purpose is simply to illustrate only in a very general and simple manner the basic concepts of CPM. For a complete and thorough description of CPM, its theory, concepts, and application the reader is referred to any of the excellent references listed in the bibliography. The reader has now progressed through the early history and evolution

of CPM and then has seen how some of its principles are applied. He has further been introduced to possible sophisticated additions to the use of CPM; regardless of whether or not such refinements are adopted by the construction industry. It is exactly this point which leads the reader into the basic heart of this paper and its purpose, which is to determine the thoughts and impressions of the construction industry at large with regard to CPM based upon its experiences over the past two years. Let us now turn to just that area.

CHAPTER 3

METHOD OF FEEDBACK

3.1 Questionnaire and Presentation

In order for a study such as this to be at all worthwhile, it was determined that some objective medium of gathering information had to be developed. This would insure that all companies questioned would present their views in a more or less constant manner, and would thus allow effective analysis of the entire group on a basis of equal effective merit. With this in mind, a written questionnaire was decided upon as the best manner of eliminating any bias on the part of the person conducting the interview, as well as that of the interviewee. This method does, however, present one disadvantage in that the participating companies were forced to conform to the format of the question sheet; thus, the layout of the material needed was of the utmost importance.

The questionnaire itself was divided into nine major portions. The first of these was of a biographic nature in that it involved statistical information on each of the companies. This would prevent comparison, in the analysis, of firms which were obviously not at all similar in nature. Included here were such points as annual volume of work and primary geographical areas of influence. This was followed by a section on electronic data processing characteristics of the firms. In today's computer-oriented business world, the need for

such a section is obvious. Then followed an area which attempted to determine the current CPM background of each company, which was coupled with a usage analysis of each firm's CPM procedures, if applicable. Then came a most important area concerning executive management participation in the CPM field, with great stress placed upon the word executive. The present CPM control procedures in use by each firm were then discussed, followed by a determination of total company involvement in CPM. Construction specification requirements concerning CPM procedures were then studied. Finally a summary portion was presented to gather the firms' overall evaluation of CPM, along with an area which allowed each firm to present its own unbound thoughts and reccomendations. It is felt that this questionnaire concept did indeed fulfill the requirements of this writer; and as such, its general format will also be followed in writing this paper itself.

3.3 Interview Procedure

In all, the sample space, which forms the basis for this paper, is composed of thirty-one construction companies in most every type of specialty work. It was felt, in order to be sure of thorough participation, that the method of personal interview was to be preferred. Twenty-one of the companies were indeed contacted in this manner by the author. These firms were either based in the New England area, or had offices located in New England. In order to gain a broader cross section, it was decided that firms based across

the nation and in Canada also be included in this analysis and report. For this reason the written interview procedure via the mails was utilized. Ten major companies participated in this manner.

In every company it was imperative that completion of the questionnaire be approved by a member of the executive management group. Also, it was requested that the interview also be conducted with a member of executive management. The cooperation on the part of the participating companies was outstanding. In over ninety percent of the firms, the official interviewed was either the firm president or one of the vice-presidents. For a complete analysis, however, such personnel as project managers, field superintendents, and field engineers were requested to participate whenever possible. Throughout this paper the author cannot praise enough the participating companies for their outstanding cooperation and willingness to freely reveal a great deal of worthwhile information. This proved to be a true highlight of the research phase of this report.

3.3 Description of Companies

Although most firms were very willing to have their names revealed herein, for the benefit of uniformity, a general rule was agreed upon which prevents such disclosures. The combined annual volume of work of the participating firms comes to an amount in excess of one and one quarter billion dollars, or approximately one and one half percent of the amount expended for construction in the United States last year

for all types of work. This further represents over two percent of the amount expended for new construction. Individual companies ranged from annual volumes in excess of two hundred million dollars down to a couple of firms whose total was in the vicinity of one million dollars.

The types of work further displayed a tremendous variety. Seventeen organizations were engaged primarily in the area of building construction, five fell into the class of heavy construction, and four were industrial constructors. The remaining five companies were involved in mechanical or electrical specialties and were primarily engaged in subcontract types of work. All the firms in general engaged in all types of contractural relationships from lump-sum bid work through the entire range to strict negotiated cost-plus arrangements.

The firms were home based from coast to coast on the North American Continent, including Canada. There was a definite majority of New England based companies; however, most of these were smaller in size, with three exceptions. The larger companies were from such diverse points as the Gulf Coast, Pacific area, mid-west, central Canada, and middle Atlantic regions. These companies literally operated on a world-wide basis, with work currently underway on all the continents with the exception of Antarctica.

3.4 CPM Cross-Section and Summary

The CPM experiences of the firms presented the entire gamut of possibilities. Some use CPM in all instances, some only when required,

some have used it and no longer do so, some vary from project to project, and some have only participated slightly in CPM controlled jobs. In summary it is felt that this survey has indeed contacted a true cross-section of the construction industry in this country and its data and results consequently should be of some bearing in future years to construction companies, specification writers, and students of the construction process.

CHAPTER 4

ANALYSIS OF ELECTRONIC DATA PROCESSING

4.1 Background and Trends

In recent years the concept of electronic data processing systems has had a most significant impact upon the greater business world, and to a certain extent the construction industry as well. One could surely state, with little fear of being greatly in error, that computer systems are an important part of tomorrow's business operations. Computer technology is further growing at a fantastic rate and is sure to result in greater construction industry applications.

Let us delve a little more deeply into this revolutionary concept. Few inventions have moved into such a variety of jobs in so many different fields at such speed, as have computers. Business and government are now spending almost four billion dollars per year for electronic processing systems, and no real slowdown is foreseen. Needless to say, such growth has also brought about a need for a whole new set of conditions for running both business and government. In addition such growth has also brought along the expected problems, such as the cost of automated systems, and the fact that they are not at all the long-awaited manager's dream of the arrival of a "cure-all".

Just how does all this fit into the plans and needs of the construction industry, with all its supposed distinct and peculiar problems? Naturally the computer could possibly find uses in the normal or now

well-known fields of business data processing such as payrolls, inventory records, accounting, etc. An additional area concerns the subject content of this paper. Various manufacturers have written programs whose purposes are to develop critical path schedules, and process related information. Electronic data processing also entails the area of collection of various forms of information for analysis and actual processing by subscription. We shall now explore each of these areas based upon the survey of the construction industry included in this report.

4.2 Company Owned Processing Equipment

The firms were asked if they owned or rented any electronic data processing equipment which was located on company premises. Of the companies responding, only five percent stated that they maintained computer facilities on company premises in continual operation. Naturally these were firms of exceptional magnitude, but even their systems were of the smaller variety and not comparable to the large installations which are today available in the particular area. Of those firms answering in the negative, the general thought was portrayed in a most repetitive and trend forming manner, and then was a feeling of real doubt. Is the computer as worthwhile as the salesmen all state? Is our firm able to maintain a workload which would justify computer costs of either rental or purchase? Are we able to afford just such a large outlay of cash? Is not such a machine lacking in the [illegible] qualities necessary in construction, namely good judgment, [illegible] ability to take corrective action?

In short, most firms simply felt that the acquisition of a computer, through purchase or a rental contract, was simply too risky and possibly not at all beneficial. This writer does feel, when one considers the average profit margin magnitudes in construction, that the permanence of a computer purchase or rental contract is indeed risky. Many firms in other lines of endeavor have paid serious penalties as a result of computer mismanagement. For smaller companies such a high overhead item is simply out of the question; and even the largest companies must also conduct a most thorough economic analysis before deciding on such an installation. Once made, such a choise greatly affects future company operations in almost all regards.

Concerning the beneficial aspects of such a system, one must admit that virtually limitless possibilities do exist, bound only by the resources and imagination of company management.

4.3 Concept of Computer Usage Centers

The firms were then asked if they made attempts at renting computer time from so-called computer usage centers, which are most common in large cities or in the vicinity of well known universities. The answers were broken down into two areas. The first concerned uses in the conventional business application areas such as payrolls. Only twenty-five percent of the firms had ever even attempted to use such centers in this manner. This seems to reflect the general conservative nature of construction companies, particularly those run by older, less impressed officers.

The companies were then asked if they utilized such centers with regard to CPM analysis applications. All those who answered in the affirmative to the above question did so again here, along with a few more companies, as the positive figure had now risen to forty-five percent. A major reason for such a rise lies in the fact that CPM computations are of a relatively new and strange nature. While business operations were most familiar, and changes did not seem needed; when CPM uses were adopted, the computational algorithm was both novel and somewhat cumbersome, especially if much updating were to be performed. Companies then sought computational assistance, sometimes at the urging of CPM consultants called in to aid in devising the diagram during the planning phase. The centers most frequented were those operated by the major computer manufacturers such as International Business Machines and General Electric, and in a few instances, smaller local firms. Major advantages to such use were the neat and readable, but at times very strange looking, output schedules. By strange, it is meant to state that such computer outputs were, at first, most perplexing to construction personnel. This problem has been largely overcome since the computer manufacturers and programmers have joined forces with construction personnel to fulfill the industry's needs within the machines' capabilities. A much mentioned disadvantage to such computer center uses was the lengthy "turn-around" times. Turn-around time is that period from the moment a firm submits its Arrow

diagram data until it receives its completed output tableau. Steps are currently underway to decrease this time; however, there will still be a lengthy physical limiting point, unless a common usage scheme such as time-sharing is implemented. In general, trends seem to indicate an increase in the use of such centers in handling complicated projects, while simple or basic jobs seem to be more and more performed by means of hand calculations, as the firms become more accustomed to the computations inherent in CPM network analysis.

4.4 Data Transmission

In reply to a question concerning the use of such data transmission facilities as the Bell "Data-Phone", not one firm indicated that it had even attempted such a technique to relay information from field to office. Such information transmitted could be, perhaps, time records, material arrivals, progress, or delays. Such a scheme could be most helpful to a company which has taken on work in an area outside its normal geographical sphere, and some distance away. Most companies frankly admitted that they were not at all aware that such systems were available, and did seem to feel that the idea was worth further analysis by the firm. One company was working out a scheme with its computer rental center, which would enable its field personnel to transmit daily changes to the CPM network directly to the computation point. In such cases the relative importance of the project must justify the costs of data transmission. The writer does feel, however, that the use of

such data transmission facilities will be vastly increased in the very near future.

4.5 Summary

In general it is felt that the construction industry will be fairly slow in jumping upon the electronic data processing bandwagon, primarily due to three causes. First the construction industry is reserved and conservative and has a more or less "wait and see" attitude. Secondly, the work itself is most diverse in nature and company managements feel, right or wrong, that it does not lend itself to automation. Lastly, the very size of many construction companies precludes the purchase of, or entrance into, rental agreements for such expensive installations.

An increasing use will, however, be made of computer time rental centers, particularly on complicated projects. This will become more prevalent as a larger number of firms become more proficient in the uses of CPM. Time-sharing installations seem to be the answer to the problem of the necessary reduction of turn-around times. Such arrangements will eventually prove very satisfactory, and at a relatively low cost. It is further felt that the use of data transmission facilities will also be increased as the uses of CPM become more universally accepted.

CHAPTER 5

COMPANY CPM BACKGROUNDS

5.1 Company CPM Introduction

As a starting point in this phase, the companies were questioned pertaining to the areas in which they were introduced to CPM; and as one will see in the following results, this presented a spectrum of great variation. In summary the results read as follows; periodical literature, sixty-five percent; academic institutions or CPM courses, twelve percent; trade or professional societies, eleven percent; and from miscellaneous sources, twelve percent. As would be expected, every company contacted had at least heard of CPM from some source, be it authoritative or not.

Regarding the areas of periodical literature, some comment is indeed in order. As was brought forth in the introduction to this paper, it was in an attempt to improve upon the results of many of these articles that this work was undertaken. Most of these articles simply were not at all general enough in character to be of great value. In almost all instances, they simply presented the views of a particular constructor or project administrator concerning a specific contract, with a rather heavy bias toward those with successful results. In actual practice, more than one firm has been seriously led astray when attempting to apply said articles to his own theatre of work. In all fairness,

it must be stated that these reports did fulfill a fairly important task. They served as a sort of "herald" for CPM among the construction industry, and they also helped breakdown the natural conservative and resistive tendencies of many construction personnel. To this end, it is felt that such articles are informative and worthwhile, and probably should be continued to the extent that they induce appropriate personnel to seek further information and assistance concerning the respective problem areas of note. It cannot be emphasized too strongly, that these reports are not at all substantive enough to be utilized as guide lines for a firm attempting its first venture with CPM. The negative results of companies contacted which attempted this approach should be ample warning for the wary.

Where does one turn for true authoritative and instructive information? The survey results seem to point to two prime sources: appropriate academic institutions and professional or trade societies, along with the specific CPM course of instruction offered by these groups. It is the specific goal of these two sources to formulate and present new concepts, such as CPM, in the best manner possible, with as little personal bias as possible. The universities are naturally well versed in CPM concepts due in no small part to their capable staff personnel, who spend parts of lifetimes attempting to test, evaluate, improve upon, and present such new tools as CPM. Their effective teaching skills are also most appropriate in planning

and presenting the so-called CPM courses. These courses, usually a week or two in length, present the entire concept of CPM to class groups of broadly diverse backgrounds in a most respectable manner. They all cover every aspect of CPM which could possibly be applied in the construction field, and the course student need merely rule out those portions which he feels do not apply to his particular firm. The moderate cost of such courses is also an added incentive. Firms which have sent personnel to such seminars, in almost all cases, report that the investments have already returned outstanding dividends in terms of improved job control procedures and smoother administration of projects. It is strongly recommended that all company key personnel, including project superintendents, be sent to such course presentations, even if only for illustrative purposes. The comments made above apply with equal emphasis to the true trade and professional societies such as the Associated General Contractors, in most every regard. The resources of such groups have been turned in great degree toward analyzing CPM procedures and instructing their members as to their proper and effective applications. Some constructors were more inclined to rely on this source, rather than the academic groups, because they felt more at home in these familiar surroundings. This idea has great merit, particularly when one considers the points of views of most job superintendents. Regardless of whether they be academic or trade groups, the courses outlined above, it is felt, are of great value to all concerned.

Two final points will now be discussed. The first of these concerns the passing along of CPM information between or among two or more companies, and only a few words are needed. Such promulgation usually results from joint venture contracts or simple friendly and competitive discussions. When accepting these comments, one must be very objective and make every effort to analyze them with regard to one's own operations, and not those of the reporting firm. Many of the same pitfalls are present here as were so in the concept of dissemination by means of periodical articles.

As a final point let us discuss the results of two firms contacted, which received their introduction to CPM in an actual contract. Both firms were awarded contracts on government projects which specified that CPM must be utilized, and neither firm had previously known that such a method had even existed. Needless to say, the results were both costly and nearly disastrous in both cases. A CPM consultant firm had to eventually be called in, with its associated expense, in order to salvage any order at all, and also in order to satisfy the government requirements. Suffice it to say that, as relatively simple a tool as CPM is, its improper and ignorant use will surely result in a most unhappy ending. At the risk of being redundant it is emphasized again that CPM is not a panacea.

5.2 CPM, Its Length of Use and Job Sizes

The companies which had already utilized CPM in their operations had done so for periods ranging from a few months to over three years, with a two year span being the most prevalent length of use. The firm with the longest span is considered by many to have been the true pioneer in implementing the uses of CPM in the construction industry. Those firms which have only recently entered the field, or have yet to do so, are the more conservatively managed companies or the smaller ones; and they have adopted a general "wait and see" attitude and have been hesitant in risking any funds in the method. Surprisingly, a few of these are relatively large firms, in terms of annual volumes of work.

The magnitude of projects which have been controlled by means of CPM ranged from fifty thousand to sixteen million dollars, with a heavy leaning to the more expensive works. It is generally felt that the smaller jobs are capable of being equally and effectively controlled by conventional means, with a lower overhead cost, except in the case of a highly complex project. This may be so, in any case, the firms contacted did state that any size job could be controlled utilizing CPM, although the results may not at times justify the cost, or more so, the added work, in the case of simple work.

5.3 Types of Construction

The sample companies had utilized CPM procedures on the following types of construction; schools, hospitals, hi-rise office buildings,

research laboratories, major commercial complexes, hotels, factories, sports centers, missile bases, military facilities, large apartment and housing complexes, highways, paving, alterations and rehabilitations. Again there existed a heavy leaning to those jobs which were complex in nature, novel in design, or those which required an intricate schedule for delivery of components or occupancy.

There also seemed to be a trend to most utilize the concepts of CPM primarily on projects dealing with building construction methods or related fields such as industrial jobs. The number of CPM controlled jobs in the area of highway, paving, or any repetitive construction works were in the definite minority. It is felt that perhaps the appropriate managers either felt that such projects were already adequately controlled by conventional means, or said managers were not as yet aware of CPM possibilities in the field of controlling material and worker arrivals. The concept of appropriate work areas for CPM will be more fully discussed later in this paper. An additional field, worthy of further research and study, concerns the applicability of CPM in corporate administrative functions. This could be a most rewarding field of endeavor; however, its discussion is beyond the scope of this text.

5.4 Was CPM Used Voluntarily?

The companies which had utilized CPM were questioned as to whether they had done so voluntarily or due to specification requirement, particularly with reference to their first CPM controlled project.

It is believed that this question is of great substance, as one's appreciation for the possible value of CPM is due in no small part to one's experience on the first contract so controlled. Thirty-five percent of the sample utilized CPM strictly in a voluntary manner, another thirty-five percent has used CPM both voluntarily and as required, and thirty percent has utilized CPM only when required to do so. A definite trend or correlation seems to present itself here. Of those firms which had only attempted the use of CPM when required, all but one reported that the results of the respective contracts were much less impressive than had been anticipated. It seems that this was due in large measure to the fact that, in these cases, the company management did not at all truly attempt to incorporate CPM into its work procedures, but was merely fulfilling the specification requirements. This concept is more fully treated in Chapter 7 of this paper. One added point, however, is that all of these firms apparently realized the actual shortcomings, and now have commenced to control contracts voluntarily by means of CPM on newer jobs, and plan to make their true evaluations based upon these unbiased trials. The group of firms which now uses CPM both voluntarily and when required had performed similar evaluation tests on their first jobs; however, in these cases, there was no inherent antagonism due to specification requirements.

5.5 CPM and Bidding

Seventy-five percent of the contacted firms stated that they never had, nor do they plan to, utilized CPM procedures in bidding a project,

prior to the contract award. The major reason given for such a negative attitude was the fact that, under the great uncertainty or low probability that the firm will actually win the bid, the expense of preparing a CPM network was thought simply too great. It is this writer's opinion that this is an over-generalized train of thought. Since bidding in itself usually requires a very thorough analysis of the job in question, one could very easily sketch out a "macroscopic" CPM network for very general uses only. One would then learn such things as the planned completion date, and possible work procedure descriptions. Such a rough schedule could be devised at almost no cost whatsoever, and it could also prove to be of great value in preparing a bid.

Of the twenty-five percent of the firms which had attempted such procedures, they are all truly sold on its benefits. One company related an interesting experience. It seemed that no contractors submitted bids on a particular lump-sum job, as they all felt that the completion date was not at all reasonable. The firm in question prepared a preliminary CPM network and found it could actually complete the project in even less time. It was able to convince the owner and architect and then proceeded to negotiate a cost-plus contract. It is sincerely recommended that contractors examine this concept of pre-bid CPM use in great detail, with expected most probable gratifying results.

5.6 Summary

This chapter explored in great detail the sources from which contractors first learned the rudiments of CPM, and also made definite recommendations for the future. It also determined such background information as length of time using CPM, the sizes of contracts, and the types of work which utilized CPM. Comments were also made regarding the uses of CPM and its variances, depending upon voluntary or specification required applications. A strong recommendation was also made on behalf of the use of CPM, at least in a rough form, in bidding procedures.

CHAPTER 6

CPM USAGE ANALYSIS

6.1 Sub-Contractors

The first topic in this chapter concerns the question of the method in which sub-contractors' portions of work fit into a CPM performance contract. It is fairly well known that this area has proven to be a probable trouble spot for all managers of construction projects, utilizing any form of attempted control. Missed starts or completion dates, improper performance, or even incompetence are not at all uncommon in this area of sub-contractor dealings. One executive seriously stated that his consumption of aspirin increased more due to sub-contractor problems than as a result of dealings with owners or architects. In attempting to control a CPM network procedure, proper inclusion of sub-contractor work is of great importance since, of the firms interviewed, roughly sixty to seventy percent of the actual construction was performed under subcontract. Many procedures were attempted as will be illustrated below.

Thirty-five percent of the companies handled the problem in a purely general manner. They did not at all attempt to determine the CPM experience or capabilities of sub-contractors, nor did they attempt to educate them nor force CPM concepts upon them. The sub-contractors are requested to furnish firm estimates of durations

for their various aspects of work. Utilizing this information as a normal time, CPM networks are developed in the accepted manner. The sub-contractors are then furnished a copy of the final schedule with their appropriate start and completion dates thereon. The respective firms reported that this method worked at least equally as well as conventional control means, although one firm did report that it had encountered serious difficulties on almost all work. This latter comment seems more in order, when one considers the amount of work done under subcontract. Of more significance is the fact that such work is usually of a specialized or highly complex nature and would thus be most prone to unexpected delays and intricate material schedules. One of the prime benefits in CPM use is its ability to aid in controlling such complex and diverse elements as would normally be performed under CPM. Thus, the method of completely ignoring CPM in the control of sub-contractors seems to be less than the ideal solution.

Sixty-five percent of the firms, however, did state that sub-contractors' subsidiary networks are an integral part of the CPM applications and are developed in a depth sufficient to achieve and maintain true overall control. The only production restriction herein is the individual sub-contractors' experience and his educational position on the CPM learning curve. The sub-contractor, it follows, must be consulted to a considerable degree in the preparation

of the schedule; and consequently, he must also be held to his schedule. These firms reported that, in almost all cases, results were generally very rewarding and each attempt in this manner showed great improvement over the last, as both the prime and sub-contractors had increased their CPM capabilities.

6.2 Major Gains with CPM

When asked what major gain is to be recognized in using CPM, just over fifty percent of the firms reported that it showed the job inter-relationships to the manager in a much more detailed manner than the Bar chart had ever been able to, as Bar chart effective use required a great deal of actual construction experience. Material delivery dates and actual arrivals could thus be more effectively planned, along with the schedule for hiring of skilled workers. In general these people felt that, in effect, CPM was simply an added tool in the bag of the managers, and it enabled him to get a better grasp of particular jobs.

Fourteen percent of the firms felt that the fact that the project superintendent and project manager were forced to become extremely well acquainted with all aspects of the job in all respects prior to the actual construction was the prime benefit in the use of CPM. Usually these men became interested in particular job portions only when trouble developed, but they now must learn a great deal about most all aspects simply in order to devise the

project network. Granted that this is an added advantage in the use of CPM, it is not felt that it should be classified as the major gain.

Yet another fourteen percent felt that the ability of CPM to pinpoint possible problem areas or delays earlier in time than previously possible was of the utmost importance. The remaining people were of the surprising opinion that CPM is best utilized in substantiating requests for extensions in job completion dates or even in verifying contractor claims before the courts. One firm reported that through the use of CPM it was able to defeat an owner's attempts to liquidate damages by proving, with its network analysis, that the delay in the actual contract completion date was in reality caused by the owner in his given directions.

The general experiences of the contacted firms was that all jobs which had utilized proper application of CPM techniques were finished within the acceptable time and cost limitations. CPM further de-emphasizes the minor time and cost-wasting activities and stresses the major controlling events. Also, all personnel concerned are working from the same program which delineates individual responsibilities and thereby eliminates a large portion of the conjecture inherent in previous conventional control methods.

6.3 Major Drawbacks of CPM

In answer to this question, seventy percent of the executives, replied that diagram updating, with its associated volumes of paper

work, was the prime drawback to the effective use of CPM. A good many of the firms which replied in this manner also added that this attitude was most prevalent in CPM required contracts, which also stated that the diagrams must be updated regularly. In reality, updating need not at all be such a great drawback, even without the use of electronic computers. There is no real need at all for the updating of diagrams in a prescribed schedule. They should be so updated only when some major job sector has radically varied from what was planned, and further job control is simply not possible by means of the present diagram. In updating, first, all completed portions of work need not be repeated on the new diagram, and those aspects yet to be accomplished may be grouped together in segments in devising the new network. Such a scheme will give adequate control information; and if more detail is required, any of the broad segment activities may be easily examined in greater detail.

Thirty percent of the firms felt that the major drawback was the cost of devising and keeping up a CPM network, including the high costs of consultant fees when necessary. Some stated that in certain jobs these costs were even greater than the benefits derived from CPM, whatever they may be. This argument does not at all seem to be valid, based upon the statements of the majority of the firms interviewed.

In all fairness it must be stated that certain firms felt there were not any real disadvantages to CPM, but they merely listed a minor

drawback in order to fully answer the question. It is this writer's opinion that the current prime difficulty in the application of CPM is that the technical state of the method itself is far superior to its rate of absorption by the operational forces.

6.4 Diagram Updating

Updating frequency is of course a completely variable matter depending entirely upon the job in question. The question was presented to merely determine if updating was practical at all, or if it were accomplished on a regular time basis regardless of the need or urgency. There was an almost completely even split among the companies on this topic with one third of them updating only when required due to vast job problems, one third updating on a strict time basis such as weekly or monthly, and the remainder of the firms following a course of complete lack of updating regardless of the situation at hand. The major conclusion reached as a result of this question is that updating frequency should be determined strictly in conformity with the pre-calculated probability of work difficulty. This is to say that a high-risk contract which is programmed in great depth, with a very restricting time limitation, would be reviewed very often and updated as needed. A less demanding project, however, would be reviewed less frequently, which would probably result in less frequent updating.

6.5 Concurrent Use of Bar Charts

The interviewees were asked if Bar or Gannt charts were drawn up and used for control purposes of any sort concurrently with the CPM network. Fully eighty-five percent of the firms stated that Bar charts were indeed drawn up along with the networks, and most of these companies used them to assist in controlling the work, as they were still "feeling their way" in the use of CPM. A few firms stated that the charts were drawn for display purposes only or to demonstrate progress to owners who did not fully understand the operations of a CPM network. Some drew up said charts for the benefit of foremen or workers who were more accustomed to working from these guides. The major computer manufacturers recognize this tendency as they have developed CPM programs which print a modified Bar chart output along with the CPM schedule. The Bar charts drawn from CPM networks are basically more precise and easier to draw than the non-CPM devised charts. If CPM becomes more generally accepted in future years, this redundant effort will almost surely become non-existent. The Bar chart will, however, still remain the prime control document on fairly simple jobs for which CPM networks are not developed.

6.6 Company Training Programs

We shall now consider the most important concept of proper and complete indoctrination or education of company personnel, particularly the worker-manager individual as represented by the job superintendent,

in the field of CPM techniques and implementation. It is most evident that any procedure or method, regardless of its potential, cannot be effectively employed unless the personnel concerned have at least a basic knowledge of the particular tool's operations. Considering such a diverse and different construction scheduling tool as CPM, the idea of proper education is most important. One must naturally know what CPM is and be aware of its limitations in order to devise a network diagram, and management personnel must be aware of the many CPM components.

In addition to this well known concept, CPM presents an added subtle problem. In most all construction projects, it is the true skilled worker, the construction superintendent, who actually directs and controls all productive labor. It is this man who is the true "boss" in the eyes of the worker, and he "get things done". The companies report that one of the permanent problems which must be overcome in introducing CPM is the strong antagonism displayed by superintendents toward this new tool developed, not in the field, but in the conference room. These men, then, must be effectively taught the basic rudiments of CPM as a definite prerequisite to its successful use. They need not at all learn the theory of CPM, but they must be aware of its general capabilities, limitations, and procedures.

Sixteen percent of the companies reported that they employed no training program of any kind, be it a form of definite CPM courses, or informal company meetings. The primary defense put forth was that the costs were too great and men such as project superintendents could not be released for a period of time to attend lectures. This is not at all valid, as such education could occur in short time intervals such as one hour per week, or even between the duration of actual contracts. It is interesting to note that these firms were those which felt that CPM was only of very limited usefulness at best. Another sixty percent of the companies reported that they persued active training programs, but included only office personnel in said sessions. Field people were excluded on the premise that they were either unwilling or incapable of accepting such a technique. These companies for the most part were those which reported great antagonism on the part of superintendents in implementing CPM. The remaining twenty-four percent had setup vigorous educational procedures for all concerned personnel, and they reported that the results were most gratifying. In summary, it is felt that superintendents and engineers should work extensively on perfecting CPM procedures between jobs, and that all newly hired personnel should attend the formal or semi-formal courses offered by many sources. Exactly this trend seems to be appearing to a great extent in all large companies.

6.7 Experience with CPM Consultants

The firms were questioned concerning the use of CPM consultants. Seventy percent reported that either they had never utilized consultants in this area, or they had done so only on their first CPM contracts. Another fifteen percent had attempted such use on more than one job; however, the results were generally poor. The major faults mentioned were the seemingly high costs of such services, and the lack of real construction experience or ability on the part of most consultants. In many instances these advisors had to be "spoon-fed" concerning construction procedures. Fifteen percent of the firms, all of relatively small size, reported continued successful use of consultant firms. It must be stated that the availability of such sources of assistance is worthwhile, even if used only to bail out a firm which has run into unexpected difficulty. More will be said of this idea later in this paper.

6.8 CPM and Project Cost Curves (Crashing)

Only two firms reported that project cost curve extensions of CPM were employed in any manner. Even these firms were only projecting such items as manloading costs, total costs, and cash flows. The prevailing thought expressed was that construction is simply too unpredictable in most regards to allow further refinement of CPM into such areas of true crash-cost curves. The input

data would only be a very rough estimate, and any such attempts would be futile. The writer is very much inclined to agree.

CHAPTER 7

EXECUTIVE MANAGEMENT PARTICIPATION AND CONTROL PROCEDURES

7.1 Executive Involvement

An important basic precept of administrative theory states in effect that, if any administrative procedure is to succeed at all, its concepts must be truly and completely upheld, pressured, and enforced by the highest echelons of company executive management. With regard to such a novel concept as CPM, the above recommendation is of great importance. Regardless of the amount of CPM support expressed by project managers, its effective implementation will result only when the executive of the firm also display great enthusiasm in the concept. These executives must further strongly publicize the fact that they truly desire that CPM be accepted and successfully implemented; and, if any failures do result, the executive must demand to know the reasons, and he must further take steps to correct any faults. Only through such constant vigilance and aggressive executive forcefulness can CPM be effectively implemented.

The interviewed companies were asked if CPM systems time was spent by executive management in proportion to costs and/or expected potentials. Fully seventy percent reported that this was not at all done. Reasons given varied from explanations of apology for the conservative nature of the company management to attempts

to pass the fault on to the facts that most executives were fairly old and most content with traditional control methods. Unless such executive traditions are overcome with bold and calculated efforts, true CPM implementations will not result in company efforts. The firms which had the desired executive participation reported that CPM activity progress was reported on a regular basis, either daily or weekly. Executive management then would react with effective remedial checks if significant deteriorating trends or variations developed.

7.2 CPM Division Responsibility

In all but three cases the responsibility for devising the CPM project networks and effecting its control rested where it truly belonged, in the construction or operations division of the firm. Individual responsibility was usually delegated to the individual project manager. It is felt that this is the desired method, as it is just this area of the corporation that must utilize the CPM capabilities and should, therefore, maintain overall control and responsibility for their operation. Two firms varied this slightly by resting CPM responsibility upon the shoulders of the chief engineer. One firm stated that overall control of CPM use was left to the procurement office. While these variations may have some merit, it is considered that the former technique is most desireable.

In order to truly wield responsibility in implementing CPM, the highest officer in the area responsible for CPM operations must

be of adequate rank in the company corporate chain to be able to present his thoughts effectively to the chief executive officer. Fifty percent of the companies reported that the chief CPM coordinator was on the second level of the corporate ladder, usually in the person of a company vice-president. The remaining fifty percent had lowered the responsibility one notch, to the third level of corporate structure. From this result it would appear that so long as the CPM executive is positioned high enough to have corporate stature, the CPM effort can truly succeed, provided this man plays an effective role and is given the kind of top management leadership already described.

7.3 CPM Post-Job Follow Up

The firms were requested to state if the use of CPM on particular jobs was followed with great effort by top management in an attempt to evaluate costs and productivity and to further attempt to evaluate any efficiency gained (or lost) by the use of CPM. Every company answered both aspects of the previous question in the same manner, either in the affirmative or negative. This is to state that there were no split replies with a yes to one part and a no to the other. Seventy percent of the firms stated that they did not attempt any formal post-job results analyses; rather they attempted to draw out some form of correlation from the overall contract profit rate. They felt that any more detailed analysis was not at all possible. Thirty percent of the interviewees did attempt some sort of review such as weekly

cost checks and complete monthly appraisals, followed by extensive post-job statistical and cost evaluation attempts. The results varied considerably, with no conclusive statements possible. Research into this area in an attempt to devise a worthy procedure is certainly deemed desireable.

7.4 CPM Cost Accounting

All but one of the firms stated that they did not attempt to account for CPM expense items in a particular cost-account category. It was considered that such CPM efforts were in the area of normal management functions, and as such should be accounted for in the normal method for such staff or overhead cost items. Most firms followed some scheme of pro-rating distinguishable CPM costs on a distribution method to each job. Of course computer time or consultant costs are easily segregated and usually are so accounted for, allowing for easy post-job cost comparisons. One company does follow a strict procedure of accounting for all CPM associated expenses, to the extent possible, in a specific category. This included time spent on CPM by project managers and similar personnel. Perhaps such a system is possible for small firms on smaller jobs, but it is felt that such a technique could be too cumbersome on a major contract.

7.5 CPM Group Control

While CPM sector personnel must be able to operate without undue restraints, they should not of course operate with complete

freedom of action. They must strictly coordinate their actions with other divisions, such as purchasing, and as such should be subject to at least normal control procedures. Most all firms indicated that there existed virtually no formal control procedure as such in this area. The primary criterion was that of the final profitability of the particular contract, since it was most difficult to effectively control such an operation as CPM planning and scheduling. This is not the optimum procedure. One company did develop a formal delineation of checks and balances, with excellent results, which is worthy of documentation. Therein, each CPM job program and updating had to be agreed upon by the job superintendent, the project operations manager, the chief of operations, and then approved by the director of construction before publication. Remedial recommendations are then made by the CPM programming manager, a decision is made, and action is then directed by the director of construction. This procedure is of course designed for larger companies. Such close control is naturally not necessary, nor desired, in the administration of a smaller company.

7.6 CPM and Particular Job Feasibility

It is granted that CPM is probably not equally applicable to all types and sizes of construction projects. There are many variables, large or small, which would effect this measure. Therefore a thorough feasibility report for each prospective job, indicating

anticipated costs, benefits, and risks is possibly to be desired. The survey brought forth three general theses in this area. First there were the firms which really did not believe in CPM usefulness and used it only on specification required contracts, hence no true feasibility study. The second group was composed of the companies which still had doubts about CPM, and these attempted to determine if CPM truly applied to a particular job before making a decision concerning its use. The third group more or less adopted CPM as standard procedure, and it attempted to isolate those jobs to which CPM definitely did not apply.

The firms stated that very few areas were not suitable for CPM application of some sort. They did in general, however, seem to specify some limiting type of concept concerning jobs in which the use of CPM would not be worthwhile. This seemed to be any job below some minimum dollar value, which varied with the size of the company, without a time or cost restriction, and no reasonably defined scope. The reader can see that this area is still very much open to great debate. Specific corporate ability would play a large part in any such decision.

CHAPTER 8

COMPANY INVOLVEMENT

8.1 Field Personnel

As was stated earlier the most prominent problem persisting in the field applications of CPM is the strong antagonism toward its implementation displayed by most all project superintendents. These men, for the most part, have worked themselves up to their present position in true labor force fashion, having begun work as apprentices or laborers. Only a very few of them are civil engineering graduates, but rather their education was earned through hard work and many years in the field. It is only natural, therefore, that they should resist any new method which was not field developed, particularly CPM which was pushed primarily by the so-called sophisticated engineers or systems analysts. The project superintendent feels that close control and progress in construction projects is due in no small part to his vast experience, and a method similar to CPM will allow an upstart engineer to control projects. This of course is far from fact, but the element of job security is a very strong motivating force.

Early attempts at CPM use did not at all aid in overcoming this antagonism. In most cases the network diagram was entirely devised in the office by engineers and consultants, with no participation whatsoever by the job superintendent. It was then thrust

upon him for implementation. Thus he was saddled with a device about which he knew nothing, and he had nothing at all to do with its inception. The natural result ensued. He was far from enthusiastic in using CPM, if he used it at all; and he was very prompt in putting the blame for any construction difficulties upon CPM and its advocates. This entire method of operating, of course, is wrong, and it must not be continued for CPM to succeed.

This defect was recognized quite early by most firms, and preventative measures were attempted. Seventy-five percent of the companies contacted did state that the project superintendent, and sometimes other field personnel, were included in the group which devised the network diagram. He, in most of these cases, played a major role. Thus he was made to feel that this new CPM technique was his tool as well as that of the organization. He now felt that it was his responsibility to see that the method was a success in the field, if at all possible. The firms reported that great improvement in CPM use definitely resulted. It was disturbing to the writer to learn that twenty-five percent of the firms had not as yet included the job superintendent in CPM work. It was, however, this type firm which reported that CPM was of little value to it in its operations. Some of these firms had only performed one or two contracts utilizing CPM, and their procedures surely will be improved.

More and more companies are elevating field superintendents and other field personnel to positions in the CPM operations group, usually in the company construction division. Such close liason is highly recommended. In summary, complete success in the use of CPM will never be achieved unless the personnel who are required to employ its outputs are included in the group which does the actual planning and scheduling.

8.2 Responsibility for Success or Failure

The companies were requested to report in which of four areas the responsibility for success or failure in the use of CPM rested. The four areas were: CPM development group, executive management, field superintendent, or CPM itself. Based upon what has been stated thus far, one would expect that said responsibility should rest with company management and/or the field personnel, and an interesting profile did result. Forty-five percent of the firms placed this responsibility upon the field superintendent, some of these being companies which did not include this man in the group which devised the network. No effective explanations of this practice were presented, other than the concept that the job superintendent is always responsible for his contracts. Another forty-five percent placed responsibility with company executive management, while ten percent pointed toward the group which devised the network. Important to note is the fact that none placed blame upon CPM itself. This would lead one to conclude that all firms feel that CPM is a definite workable

tool, and the quality of its success rests solely with the manner in which each company employs its concepts.

8.3 Group Manager's Background

With today's great emphasis upon job specialization, a question was asked of the interviewees which attempted to learn the general background of the manager of the CPM group, so-called. This was an effort to determine if the companies had brought in outside specialists to head up their groups, such as CPM consultants or systems analysts, in lieu of keeping control in the hands of construction people, where it surely belongs. The latter recommended individual indeed was the group leader in every company. None of those interviewed had hired people from outside the construction industry. The typical manager was a graduate civil engineer, with a few holding advanced degrees in business administration. Some had further education in the fields of programming or computer analysis. All had risen in the construction industry having held such positions as job engineer, estimator, project manager, superintendent, or general contractor. Years of construction experience varied, depending upon the company, from five to thirty. Considering the peculiar characteristics of the construction industry, it is recommended that this practice continue. Almost all the firms reported that the members of the so-called CPM group had little or no computer use background.

8.4 Company Attempted CPM Improvements

With many new techniques, the true refinements and improvements usually occur as a result of feedback from the using personnel who attempt to adopt any such method to the many and peculiar company situations. Often such efforts prove to be equally as valuable as the original proposal. With this possibility in mind the interviewees were asked if they had attempted to improve upon CPM in any particular manner. Eighty percent of the companies stated that they had not attempted any novel procedures, but were using CPM only in the manner prescribed. The other firms produced nothing of an earthshaking nature, but their refinements were interesting and did result in improved CPM use. Some of the larger firms pressed forward with continuous research, experiment, and development of basic procedures. A few of these have prepared company CPM handbooks and textbook manuals. A few devised their own manually generated Bar chart outputs from the arrow diagrams, or have attempted time scale drawn arrow diagrams, or flow diagrams which are activity oriented. One firm attempted to solve the problem of having twenty-foot diagrams, by using a normal sized notebook scheme. The first page was a macroscopic arrow diagram of the entire job, not at all in detail. Each succeeding page took an activity of the first sheet and expanded it into whatever detail was required for the job. This attempt is fairly worthy, as anyone who has attempted to work with one which

covered three walls of a room can surely state. Yet another firm had made a good attempt at overcoming the CPM antagonism of project superintendents. The superintendent was included in the group which devised the network, but an arrow diagram itself was never set up for use in the field. Instead, a sheet listing all the work activities in great detail and the planned starting and completion calendar dates was the instrument actually used by the field personnel in controlling the work. This met with great acceptance by field workers. The concept of critical activities was still very much adhered to by such office people as the project manager. These attempts illustrate that the industry truly feels that CPM is of great value, and such improvements and refinements are sure to occur on a continual basis, with expected rewarding results.

CHAPTER 9

SPECIFICATION REQUIREMENTS

9.1 Required Use of CPM

The interviewees were requested to state their views with regard to the apparent rising trend of owners and architects requiring the use of CPM on projects in specification sections. The results were generally as would be expected, with a few surprising concepts. Seventy-five percent of the contractors stated that this was not at all a good practice. The general consensus was that such a control technique as CPM was strictly an added tool available to the contractor, and its use should not be dictated by an owner. Since specifications do not spell out construction procedures, but rather minimum requirements; they also should not require any particular control method. Some builders were of the opinion that such practices by owners were inspired in many cases by the opinion of owners that the use of CPM was a current day status symbol. This is to say that owners required CPM simply because it seemed to be a more sophisticated concept. Many firms felt that such required CPM use was generally too rigidly specified with specific updating schedules regardless of the need for updating on the particular job.

A few firms had favorable opinions, such as the thought that the required use of CPM was the first realistic approach to construction taken by architects in many years; however, even these firms

indicated that there should be certain factors which must be considered in continuing this practice. First, the owner must be fully aware of both the capabilities and the limitations of CPM, moreover, they must be fully cognizant of the fact that CPM is not a panacea and all construction and job site problems will not now completely disappear. Firms pointed out that the owners must also be aware of the fact that they be prepared to bear any increased costs incurred in the use of CPM.

The writer believes that the majority opinion of the contractors, that CPM is a tool for the builder and not the owner, is a valid one and probably should be the general rule. A contract specification stating that CPM will be used contains latent, legal complexities which could become the basis for extensive litigation. The complexity foreseen in required CPM use is basically contained in the fact that the myriad facts of technique application inherent in the present state of development generate equal quantities of varying procedure. The sum of any selected group of procedures, as may be specified by any owner, certainly will not fit the standard personnel characteristics, policies, and procedures of each contract bidder on a truly equitable basis.

9.2 Consultants and Ability

A question was asked requesting comments on the general use of CPM consultant firms. Only twenty percent of the firms reported overall

general success in the use of consultants in CPM. Some of these were required to hire consultants, because they had been awarded a CPM required use contract without ever before having attempted any use of CPM. In these instances the consultant proved to be a great aid when updating was necessary or when radical work departures were needed. In general, if a company is not familiar with CPM procedures, consultants can be most helpful in educating personnel and setting up initial procedures.

The opinion of eighty percent of the companies was that the majority of consultant firms are qualified in electronic data processing techniques and the procedures for gathering and integrating information; but they lack realistic construction understanding and, therefore, the ability to readily identify and separate important concepts from those which are of minimum importance. A construction contractor cannot afford to make important decisions from opinions and reccomendations that are apt to be saturated with uncertainties and unknowns. Costs of consultant use is also of bearing.

9.3 CPM Knowledge of Owners

The companies were asked if they felt that owners possessed a correct and ample knowledge of proper CPM uses. The companies were unanimous for the first time in this report, in the opinion that owners did not have the needed background in CPM. The concept may be summed up in a few words. The public procurement agencies at

the federal level have fundamentally correct and ample, but not necessarily proper, knowledge of CPM uses as applied to construction. Private owners have very little knowledge, as this knowledge may be gained only through experience. It is needless to say that this general concept is subject to great debate, depending upon the group with whom one is speaking. Problems in this area, however, are sure to lessen with the passage of time.

CHAPTER 10

SUMMARY AND CONCLUSION

10.1 Additional Company Comments

As the conclusion of the interviews were approached, the firms were given free rein to add any other comments which they felt could be of any importance in the general field of CPM. Some companies chose not to bring up any items at all, but most mentioned concepts worthy of some discussion. Seven of them felt very strongly that a general practice of time scaling CPM diagrams after they are completed should be adopted in order to insure that project superintendents recognize peak periods of manpower requirements. Such an attempt at overcoming the ancient problem of resource allocation is worthy of merit, at least on the larger projects. An added thought pertaining to computer usage presented itself in more than one interview. This was the logical concept that in order for computer use to be economical, it must be used for more than simply calculating the critical path and calendar dating. Perhaps a plan for integrating these capabilities with a power for determining normal and crash costs and durations, updating techniques, and normal business data processing is in order.

Despite the intriguing qualities evident in CPM upon initial examination, it is not universal in its applications to the construction industry. The tremendous impact of the overwhelming detail of

a program developed to the greatest depth is suffocating to the novice user. The new symbols and language automatically create doubt and uneasy distrust in the "hard-headed" construction man who takes great pride in considering himself an expert in his chosen field. The field operation application of CPM, therefore, will not achieve any very large measure of success until a new and more liberal generation of operational personnel has arisen; or, the gradual transition of an on-the-job training program is activated by the contractor, and not consultants. Most firms were of the opinion that, in this period of progress, academic and other proponents of the technique should expend more effort in the development of the basic communicating semantics of CPM, and less on the potential of electronic data processing.

10.2 Overall Company Evaluations

The companies were requested to give, in a definitive manner, their overall appraisals of CPM capabilities, in an attempt to gain the general feeling of the industry with regard to technique. Thirty-three percent reported that CPM had aided them greatly in controlling projects. Another fifty-five percent stated that the use of CPM had proven to be of some real value; however, certain definite limitations were currently present. A low twelve percent of the firms were of the opinion that CPM was of virtually no value to them under normal operating conditions. Thus the general opinion was similar to that which was expected, a close to normal, or bell-shaped, response curve with

a heavy leaning toward a general acceptance of CPM, with a few more conservative "foot-dragging" firms. It must be confessed that this final question was sort of "loaded" in nature, in an attempt to verify responses to earlier questions, which were most important. Two of these were types which questioned true executive management participation in CPM and also the concept of including field personnel in the group which determined the arrow diagram. The per-company correlation among such questions was most consistent. The companies which had not really attempted to gain actual CPM workability were those which reported its use to be of very little value. No more need be stated.

10.3 Simulation Survey

As a means of presenting, in a concise and compressed manner, the thoughts of the interviewed sample as a whole with regard to all the aspects of CPM, a simulation shall now be presented. We shall follow the course of a hypothetical construction firm through the entire gamut of CPM ideas from its introduction to its total implementation. All the concepts result from the opinions presented by the interviewed group.

The firm could actually be in any of the major construction fields, of virtually any size, and may operate in any geographical area. Certain variations in implementation would result depending upon the particular company's characteristics. It need not at all

employ any electronic computer on company premises or through rental centers; however, some such use could be preferred on larger or more complex projects. Data transmission equipment need not be in use, although the employment of such devices will probably increase in the future.

The company should be introduced to CPM either through formal course presentation, or at informed professional society seminars or meetings. It may use CPM on jobs of any size with probable little use made of it on repetitive, easily controlled work. A definite ability to use CPM voluntarily should be present, along with a willingness to do so. On certain critical or restricted projects, the elements of CPM should be employed as a part of bidding procedures.

In almost all cases, the sub-contractor's work portions should be a definite part of the arrow diagram. The major gain recognized through CPM would be a much closer job control, and a greater awareness of activity inter-relationships. The possible major drawback would be a difficulty in updating when required. Bar charts will probably be used concurrently, even if only for presentation purposes. A strong and complete company CPM training program must be adhered to, and its use must definitely include such field personnel as job superintendents. The use of project cost curves will probably not be extensively followed, but a progressive firm may make some attempts in this field.

It is most forcefully suggested that, in order for CPM use to succeed, company executive management personnel must be completely behind its implementation; and responsibility for CPM use should rest in the operating or construction division. Post-job follow up, in order to evaluate CPM procedures in effect, must be employed on every project. In this way management would obtain the needed control over CPM operations on a regular basis. In addition, true job feasibility studies should be performed prior to the commencement of employing CPM techniques on any marginal projects.

The project superintendent must, without exception, be included when the arrow diagram is drawn up, in order that he accept the method as his own to a certain degree. The responsibility for the eventual success or failure of CPM implementation on a project should be carried jointly by company executive management and the project superintendent. The company further should attempt to improve upon and modify CPM use as necessary to suit its own long-run goals.

The company will probably be of the opinion that CPM is strictly a tool of [illegible], and rightly so. It may further employ consultant firms in the initial indoctrination period, but it will cease such practice after having set up its own effective CPM procedural outline. By following such a very compressed series of operations as listed above, the newly introduced firm will very probably be of the opinion that CPM use is of great

value in planning, scheduling, and controlling most all construction projects encountered.

10.4 Statistical Summary and Conclusion

The reader is now referred to Figure 10.1, which is a summary statistical tableau of the main points of this paper. Across the top of the matrix are the overall evaluations of the firms with regard to CPM. These are: a great aid, of some value, and of little value at best. The left side presents seven key concepts, and displays the answers in percentages related to the respective evaluations. From this, one is expected to be able to derive some self-evident conclusions.

The ownership or on-site rental of computer systems seems to play little part in the successful implementation of CPM; although this could be subject to change in the future. The use of CPM rental centers does, however, seem to play a part. The more successful firms did employ such means to a relevant degree. The use of Bar charts concurrently with CPM, and the employment of CPM in bidding procedures follow a similar pattern but to a lesser degree; and are probably not points of great importance.

The remaining three issues are the true keys to proper and successful implementation of CPM. There was unanimous agreement on the part of the firms which felt CPM to be a great tool, concerning these concepts. There must be a vigorous CPM training program in

COMPANY CPM EVALUATIONS

	Aided Firm Greatly		Of Some Value		Of Little Value	
	Yes	No	Yes	No	Yes	No
Does company own or rent computers on firm premises?	17	83	0	100	0	100
Does firm make use of computer rental centers for CPM use?	[illegible]	20	50	50	0	100
Are Bar charts used concurrently with CPM?	65	35	90	10	100	0
Is there a vigorous company CPM training program?	100	0	80	20	0	100
Is CPM systems time spent by firm executive management to great degree?	100	0	50	50	30	70
Are field personnel included in making up Arrow diagram?	100	0	50	50	0	100
Is CPM used in bidding procedures?	50	50	20	80	0	100

(All Figures Expressed As Percents)

STATISTICAL COMPARISON SUMMARY

Figure 10.1

force for field as well as office personnel; company executive management must truly back CPM concepts and spend appropriate time in this area, and field personnel must be included in the group which devises the Arrow diagram at the start. The firms which used CPM with only some nominal success seemed to generally hold these same opinions, but with much less overall agreement. Most important to note is the fact that those firms which felt CPM was virtually of no value were in direct disagreement with these basic conclusions in every respect. To use a definite cliche, the figures speak with great force.

10.5 Conclusion

At this point the reader has surely been able to grasp the general opinions and procedures in effect with regard to the critical path method in the construction industry. He has learned of poor, as well as good practice, herein defined in a relative manner. He has had recommendations for improvements presented to him, based upon the feelings of the interviewed sample. It is sincerely hoped that this report has shed some light upon the field of CPM use, from the point of view of the actual user, the construction industry. It is further desired that this report will result in improved practice by both the owner-architect-engineer, and the construction contractor. This report is by no means all inclusive and the end of further quests for greater refinement. Any of the many areas touched upon herein, lend themselves quite readily to greater research and effort. It is

finally requested that much more detailed work be undertaken in the immediate future for the ultimate benefit of all those concerned with the great and wonderful construction industry, with which I am most proud to associate myself.

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APPENDICES

APPENDIX 1

CPM - GLOSSARY OF TERMS

Activity - a specific item of work which must be completed prior to the start of a subsequent activity

Crash Cost - cost to perform an activity at crash time

Crash Time - shortest time in which an activity may be completed assuming infinite resources, or management imposed limits

Critical Activity - an activity for which an increase in duration would cause equal increase in total project duration

Critical Path - a collection of connected critical activities from origin to terminal node

Duration - the time in which an activity is scheduled to be completed

Earliest Event Time - the earliest point in time that an activity can be completed if all preceding activities are completed in scheduled durations

Early Finish - is earliest point in time that an activity can be completed if all preceding activities are done in their scheduled durations

Early Start - earliest point in time that an activity can be started if all preceding activities are done in their scheduled duration

Event - a starting or ending point of an activity or string of activities - events correspond to nodes

Float - the amount of extra time available to perform an activity without delaying project completion

Floater - an activity which has float and is not critical

Free Float - the amount of time an activity can be lengthened without affecting the earliest starting time of any succeeding activity

Independent Float - the amount of time an activity can be lengthened without affecting the possible starts or finishes of any other activity in the network

Late Finish - latest point in time that an activity can be completed without delaying the scheduled project completion

Late Start - the latest point in time that an activity may start and still allow it to be completed without delaying the project completion

Latest Event Time - the latest point in time that an event may occur without lengthening the project duration

Normal Cost - the least cost for an activity

Normal Time - the activity duration of least cost

Origin - the start of a project or the point where work first commences on a project

Project - the entire goal or end, such as all the work covered by a construction contract

Project Duration - the scheduled execution time for the entire project

Slope - the cost to shorten the duration of the activity one day below a given duration

Terminus - the end of the project and signifies total project completion

Total Float - the maximum amount of time the scheduled duration of an activity can be lengthened without delaying the scheduled completion of the entire project. Its use may, however, affect the finishes or starts of any preceding or succeeding activity

APPENDIX 2

CPM USER FEEDBACK QUESTIONNAIRE

DIVISION I - COMPANY INFORMATION

1. Estimated annual volume of business.
2. Major field of construction work.
3. Percentage of subcontracted work.
4. Primary geographical area of work.

DIVISION II - ELECTRONIC DATA PROCESSING

1. Does this firm now own or rent any electronic data processing equipment which is located on company premises?
2. Is any use now being made of computer usage or rental centers?
   - a) For business or data processing purposes
   - b) For CPM uses.
3. Are you now employing any data transmission equipment (such as data-phones) to transmit data from field sites to home office or computer centers?

DIVISION III - CPM [illegible]

1. Has company heard of CPM uses? From where?
2. Has company used CPM at all?
   - a) How long?
   - b) Size of jobs?
   - c) Types of construction?
   - d) Voluntarily or due to specification requirements?
   - e) Is CPM used in bidding procedures?

DIVISION IV - CPM USAGE ANALYSIS

1. How do subcontractors' portions of work fit into a CPM performed contract?
2. What are the major gains recognized thus far in utilizing CPM?
3. What are the current major drawbacks?
4. How often are diagrams updated?

5. Are Bar or Gantt charts used concurrently with CPM on projects?
6. Is there any type of company training program in force to educate staffs in the CPM fields? (Particularly are project superintendents able to efficiently work with CPM?)
7. Has the use of consulting firms been attempted with regard to CPM? With what degree of success?
8. Is the use of CPM extended into the areas of developing project cost curves?

DIVISION V - EXECUTIVE MANAGEMENT PARTICIPATION

1. Is CPM systems time spent by executive management done so in proportion to costs and/or expected potential?
2. Which company division is responsible for CPM applications?
    a) How many levels down the corporate chain of command is the highest position in the CPM applications group?
3. Is the CPM group in the Estimating Department?
4. If the company owns or rents a computer, is CPM group closely involved with data processing people?
5. Is the use of CPM on particular jobs followed up with great effort by top management in an attempt to evaluate costs and productivity?
6. Are post-job analyses made in an attempt to realize savings and efficiencies gained (or lost) by the use of CPM?

DIVISION VI - CPM CONTROL PROCEDURES

1. How is the cost of CPM work accounted for in financial job-cost records?
2. What type of control is exercised over CPM operations group?
3. Are areas for possible CPM uses selected on the basis of feasibility studies for each job?
    a) What types are not suitable for CPM?

DIVISION VII - COMPANY INVOLVEMENT

1. Are field personnel included in the group which devises CPM network?

2. Are any ex-field personnel now members of a CPM staff?
3. Where does responsibility for CPM success or failure rest?
    a) CPM group
    b) Top management
    c) Field superintendent
    d) CPM itself
    e) Other
4. What is the CPM group manager's background?
5. What is the computer use background of CPM group?
6. Has your firm attempted to improve upon CPM use on its own in any way?

DIVISION VIII - SPECIFICATION REQUIREMENTS

1. What are your comments with regard to the rising trend of owners requiring the use of CPM on projects in specifications?
2. Comment on the general use of CPM consultant firms in planning a CPM project and during the actual construction phase.
3. Do you find that the using facilities (owners, etc.) have a correct and ample knowledge of proper CPM uses?

DIVISION IX - SUMMARY

1. Please take free will here to add any other comments you feel could be of importance in this general field of CPM.
2. Do you feel that CPM has aided your firm greatly, very little at best, or is it virtually of no great value to you?

APPENDIX 3

PARTIAL LIST OF PARTICIPATING COMPANIES

(An additional twelve firms did not permit use of company name.)

Aberthaw Construction Co.
60 State Street
Boston 9, Massachusetts

Basic Construction Co.
Headquarters
Newport News, Virginia

Beacon Construction
100 Hano Street
Allston, Massachusetts

Blount Brothers Corporation
79 Commerce Street
P. O. Box 949
Montgomery, Alabama

Franchi Construction Co.
429 Watertown Street
Newton, Massachusetts

George A. Fuller Co.
11 Beacon Street
Boston, Massachusetts
(District Office)

Jackson Construction Inc.
Old Mill Building
Newton, Massachusetts

George B. H. Macomber Company
25 Furdham Road
Allston, Massachusetts

Mills & Jones Inc.
400 23rd Street So.
P. O. Box 264
St. Petersburg, Florida

Mishara Construction Co., Inc.
169 Pine Street
East Natick, Massachusetts

Perini Corporation
73 Mt. Wayte Avenue
Framingham, Massachusetts

Perini Limited
49 Jackes Avenue
Toronto 7, Ontario
Canada

S & A Allen Construction
330 Rutherford Avenue
Charlestown, Massachusetts

Turner Construction Co.
38 Newbury Street
Boston, Massachusetts
(District Office)

Vappi and Company
240 Sidney Street
Cambridge, Massachusetts

Volpe Construction Co., Inc.
51 Eastern Avenue
Malden, Massachusetts

Warren Bros.
33 Cambridge Parkway
Cambridge, Massachusetts

Wexler Construction Company
118 Needham Street
Newton, Massachusetts

Del E. Webb Corporation
P. O. Box 39692
5101 San Fernando Road West
Los Angeles 39, California

Gaylord
SHELF BINDER
Syracuse, N. Y.
Stockton, Calif.

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